Nondestructive structure test of cam-shaft using both eddy current and X-rays

著者	Yaguchi Osamu, Okada Yoshiyuki, Sasaki Toshihiko
journal or publication title	Advanced Materials Research
volume	409
page range	590-594
year	2012-01-01
URL	http://hdl.handle.net/2297/30191

doi: 10.4028/www.scientific.net/AMR.409.590

Nondestructive Structure Test of cam-shaft using both eddy current and X-rays

Osamu YAGUCHI[1,a], Yoshiyuki OKADA[2,b], Toshihiko SASAKI[3,C]

[1]Riken Corp., 13-5,Kudankita 1-chome,chiyoda-ku,Tokyo 102-8202 Japan
[2,3]Kanazawa University, Kanazawa, Ishikawa, Japan

[a]osamu.yaguchi@riken.co.jp [b]okada-y@stu.kanazawa-u.ac.jp
[c]sasakit@kenroku.kanazawa-u.ac.jp

Keywords : Eddy Current, X-ray, Nondestructive Test, Chilled Structure, Cam-shaft

Abstract. The cam-shaft for the internal-combustion engine needs to be chilled at the foundry stage to rise the cam hardness, but unexpected chilled structures could occur on the sensor plate surface. If chilled structures exist on the sensor plate, a grinding tool may break when grinding sensor plate, or the specified shape may be unable to be produced due to resistance arising from the hyper-hardness of the chilled structures. For this reason, developing an inspection technique and a device for detecting unnecessary chilled structures before grinding the cam-shaft and for determining the rejection and removal of cam-shafts with chilled structures detected was necessary.

This article reports on a recently developed nondestructive method using an eddy current test and X-rays to accurately detect chilled structures on a cam-shaft sensor plate.

1. Summary

In the manufacturing process of a cam-shaft for the internal-combustion engine that primarily includes casting and machining, the cam tip's structures are chilled locally to increase durability and resistance to abrasion with other areas that are de-chilled in order to raise machinability. When hard chilled structures are in areas other than a cam, they could exert harmful influence on the manufacturing line due to bite damage, etc. However, since the surface of a cam-shaft immediately after casting is covered with oxide scales (black scales), it is difficult to confirm chilled structures from appearance. In our research, we conducted a basic examination to develop an optimum evaluation system for the actual cam-shaft manufacturing line. As a result, we succeeded in developing a system that can detect structures with a nondestructive method, even on a cam-shaft covered with a rough casting surface. Our report follows below.

2. Nondestructive test using eddy current

2.1 Eddy current

When a conductor is brought close to a coil running with alternating current, eddy current is inducted inside the conductor due to electromagnetic induction phenomenon. The generating eddy current decreases as it goes deeper inside the conductor. The eddy current density (Jx) at a depth (x) from the surface of a conductor is calculated by formula (1)[(3)] below.

$$J_x = J_0 \exp(-x\sqrt{\pi f \mu \sigma}) \quad \left[A/m^2\right] \tag{1}$$

J_0 : Current density of conductor surface [A/m^2]
x : Depth from the conductor surface [m]
σ : Conductor conductivity [S/m]
f : Frequency of AC magnetic field [Hz]
μ: Conductor permeability [H/m]

Chilled structure detection can be conducted by detecting the crystal structure difference or the permeability change[(1),(2)].

2.2 Eddy current sensor

The eddy current sensor we used in our research is a through hole type (φ63 mm) as shown in Fig. 1. This type measures the eddy current data by putting a specimen to be measured into the hole. Two sensors are used to inspect the structures in order to detect the permeability difference from the standard specimen.

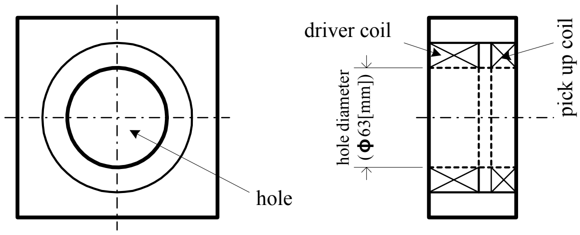


Fig.1 Through hole type eddy current sensor

3. Problem for structure distinction and solution

We discovered a problem below when inspecting a cam-shaft's sensor plate with an eddy current type nondestructive inspection apparatus.
When holding a cam-shaft with holder A/B as shown in Fig. 2, if the center shaft of holder A/B is distorted, the holding position moves slightly in the axial direction each time a cam-shaft is set on the inspection apparatus. This results in variations in X(active current) and Y(reactive current) data obtained from eddy current.

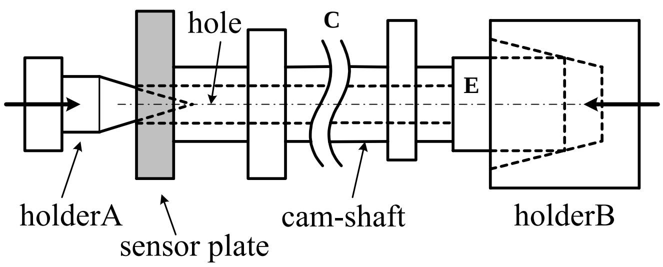


Fig.2 Example of holding cam-shaft

We considered this problem as below and conducted an experiment. With a sensor as shown in Fig.1, the magnetic field intensity (H) in the solenoid coil center is calculated by formula (2) below as shown in Fig. 3.

$$H = nI / \sqrt{1+(2r/l)^2} \quad [A/m] \tag{2}$$

n: Coiling amount per coil unit length I: Current running in coil [A]
r: Coil's radius [m] l: Coil length [m]

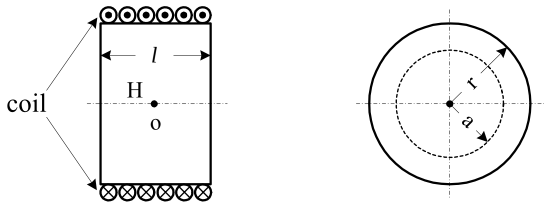


Fig.3 Magnetic field intensity in solenoid

Although the magnetic field intensity is different from formula (2), the magnetic field intensity pattern of the coil's axial direction is the same on an arbitrary concentric circle of radius a. Therefore, even if a sensor plate is moved in the coil's axial direction at the coil center (O), the intensity of the magnetic line that penetrates a sensor plate does not change. Nevertheless, the obtained eddy current data show changes. This may be because the eddy current received at a pick up coil changes. Speculating this, we conducted the following experiment. Move the cam-shaft to be inspected by approximately 0.5 [mm] to 1 [mm] in the axial direction and obtain eddy current data. Then you can observe the phenomenon of the eddy current vector making a straight-line movement in the θ direction like the locus Q in Fig. 4. Figure 4 illustrates one exciting frequency, but all the 8 waves of 25[Hz],80[Hz],250[Hz],630[Hz],1.6k[Hz],4k[Hz], 10k[Hz],and 25k[Hz] move on a straight-line.

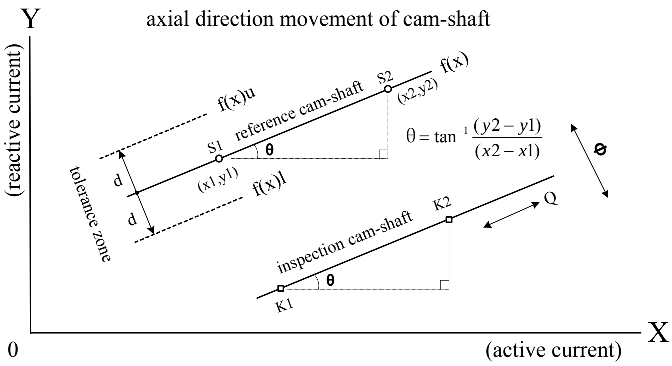


Fig.4 X,Y data for axial cam-shaft movement

We discovered the following from this experiment.

a. When the same metal specimen is moved in a through hole type eddy current sensor in the coil's axial direction, the locus of X and Y data becomes a straight line, meaning that the eddy current's phase does not change, but the signal level received changes.

b. If there is a difference in the metal structure, the structure's permeability changes. Then the phase of the eddy current received also changes, and the locus of the eddy current data becomes parallel to the inclination in a., but becomes a straight line in a different area.

Based on these results, we see that the change in the obtained eddy current data when a sensor plate is moved in the coil's axial direction at the coil center (O) is because the intensity received at the pick up coil changes to the eddy current that occurred inside the sensor plate. In Fig.4, even if the eddy current vector moves in the Q direction, this does not necessarily mean that the sensor plate's permeability changed. Also, even if the sensor plate's position is not changed, the eddy current vector moves in Φdirection if there is a difference in the sensor plate's structure. (The bigger the permeability difference is, the bigger the (vector) movement in the Φdirection) The inspection method developed this time sets the tolerance zone with the 2 parallel lines (f(x)u, andf(x)l) as shown in Fig.4.

4. Specimens and structure judgment

We prepared 3 different specimens at the chilled area rates of 0.5%,5%,and 12% as shown in Fig.5 (Chilled area rates of 0.5% or under are non-defective items) of a cam-shaft including chilled structures on the sensor plate. We examined the structure of 10 sample cam-shafts for each specimen with the nondestructive inspection apparatus for the cam-shaft that we made based on the structure inspection method we have introduced so far. As a result, all the specimens with a chilled area rate of 0.5% passed, and all the specimens with 5% and 12% failed, which is correct.

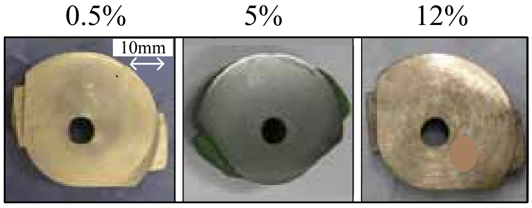


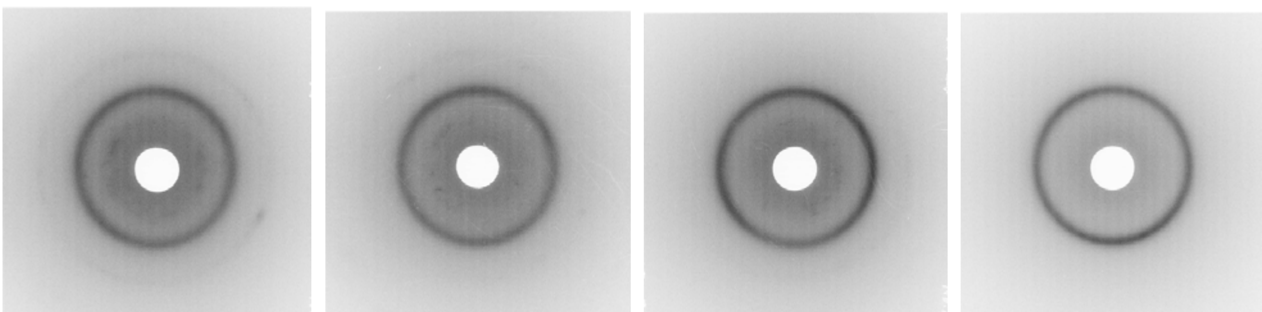
Fig.5 Sensor plate specimens

5. X-ray diffraction experiment

In order to compare with other evaluation method, X-ray diffraction method was investigated. Fig.6 shows specimens used for X-ray experiment. in the experiment, Fig.7 shows Debye ring obtained from the cam specimen. CrKα radiation and 211-diffraction were used. Debye rings were measured at different locations using an image plate. It is seen that each difference is not clearly understood in the range to have compared the photograph. Fig.8 shows diffraction profiles obtained from Each Debye ring in Fig.7. At point-A on the cam specimen, the diffraction profile shows a larger FWHM (Full Width at Half Maximum) as well as higher diffraction intensity comparing to the other points. However, the judgment of chilled structure is difficult because the difference is indistinct. Because X-ray diffraction is caused on the surface of the material, there is a possibility of receiving the influence of the surface treatment of the material.

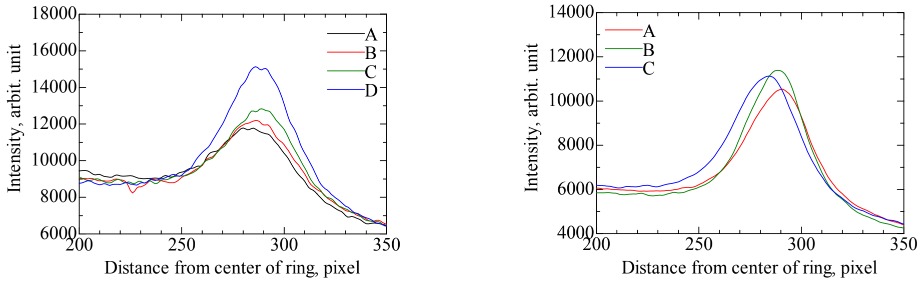
(a) cam (b) sensor plate

Fig.6 Specimens used for X-ray diffraction experiment and locations irradiated by X-rays.



(a) point-A (b) point-B (c) point-C (d) point-D

Fig.7 Debye rings obtained from the cam specimen. (CrKα radiation, 211-diffraction)



(a) cam specimen (b) sensor plate specimen

Fig.8 Diffraction profiles obtained from the cam specimen and the sensor plate specimen.

CONCLUSIONS

1. When we obtained the eddy current data, we moved the inspection item in the coil's axial direction and calculated the movement angles (θ) of X and Y data. We did not consider the eddy current data displacement in the θ direction as a change in permeability, and we were able to develop an inspection apparatus that accurately judges.

   The inspection apparatus that we developed has the following advantages:
   A) A specimen (cam-shaft) with a rough casting surface after casting can be inspected.
   B) The detection of structure differences does not deteriorate even if the center of the inspection apparatus's holder axis is incorrect for reasons such as the structure having been incorrectly manufactured or having changed after long use.

   This is extremely useful as a technology for detecting chilled structures on a sensor plate.

2. The volume of self-induction voltage (υ) that occurs on a pick up coil is in proportion to the change rate of the flux (Φ) inside the coil.
   $\upsilon = -k \cdot d\Phi / dt$ (k : Constant t : Time)
   Therefore, the lower the exciting frequency is, the smaller υ becomes. Also, if the drive coil's inductance (L) becomes large according to the inspection item's material and size, the inspection item is not excited fully by a high frequency, and υ becomes small. We expect an ideal eddy current type nondestructive inspection apparatus will be developed. The drive coil current will automatically adapt at each frequency so that the eddy current detection sensitivity and resolution would be almost the same at any frequency.

REFERENCES

[1] T. Abe, T. Uchimoto, T. Takagi, and S. Tada: Material Characterization of Cast Irons by Eddy Current Testing, J. JFS, Vol.75, No.10 (2003)
[2] M. Kurosawa, T. Uchimoto, T. Takagi, T. Sato, H. Kage, T. Noguchi : Detection of Cementite in Spheroidal Graphite Cast Irons Using Eddy Current Method, J.JFS, Vol.77, No.12 (2005)
[3] Crack Test using eddy current Ⅱ: The Japanese Society for Non-destructive Inspection
[4] Eddy visor SC Handbook : ibg Prüfcomputer GmbH